

GRB/HN from Kerr Black Holes in Binaries

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Abstract. The Collapsar model, in which a massive star ($\gtrsim 20M_{\odot}$) fails to produce a SN and forms a BH, provides the main framework for understanding long Gamma-Ray Bursts (GRB) and the accompanying hypernovae (HN). However, single massive-star models that explain the population of pulsars, predict cores that rotate too slowly to produce GRBs/HNe. We present a model of binary evolution that allows the formation of Kerr black holes (BH) where the spin of the BH can be estimated from the pre-collapse orbit, and use the Blandford-Znajek (BZ) mechanism to estimate the available energy for a GRB/HN.

A population synthesis study shows that this model can account for both, the long GRB and the subluminal GRB populations.

Keywords: binaries: close — gamma rays: bursts — black hole physics — supernovae: general — X-rays: binaries

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SUMMARY

We ([5], [6], [9], [12], [13]) model binaries in which the primary star (BH progenitor) evolves as a single star until its core begins He burning. When He burning begins in the core the stellar radius expands a further 10 to 15% relative to the red giant radius, it fills its Roche Lobe and begins to transfer mass to the secondary star, i.e. Case C mass transfer. As a result, the orbit shrinks and the binary goes into a common envelope. The H envelope of the primary is removed at the expense of orbital angular momentum. Eventually the orbit, originally $> 1,500R_{\odot}$, decays to a few R_{\odot} . The ratio of the stellar radius to orbital separation leads the primary to spin up by tidal synchronization. Hence, having a good estimate of the orbital period and, assuming angular momentum conservation during the collapse, one may obtain the natal Kerr parameter of the BH (see column 6 in Tab. 1 and the left (L) plot in Fig. 1).

The natal Kerr parameter may be modified by two post-formation mechanisms. The first one is by using the rotational energy to produce the GRB/HN, e.g. through the BZ mechanism [2], a GRB/HN explosion (see column 9 in 1). A drastic decrease of the natal Kerr parameter is not expected given that a small percentage of the available energy is enough to power the GRB/HN. Further constraints on the energy of the explosion can be placed through the Blaauw-Boersma kick ([1], [3]) and the fact that the binary remains bound (and, usually, has small eccentricity). The second mechanism is by accreting mass into the BH (see the right (R) plot in Fig. 1) once the secondary, or its wind, fills its Roche Lobe.

Measurements by [15] coincide with the predictions of [9] for the Kerr parameters of GRO J1655–40 and 4U 1543–47. Our estimates are consistent with the observed Kerr parameter in LMC X–3 (fig.3 in [7]), and the measurements for the Galactic GRS 1915+105 [11], as well as the extragalactic LMC X–1 [8] and M33 X–7 [10] can be explained through a phase of mass transfer (with wind mass transfer and hypercritical accretion for the last 2, see [13] and [14]).

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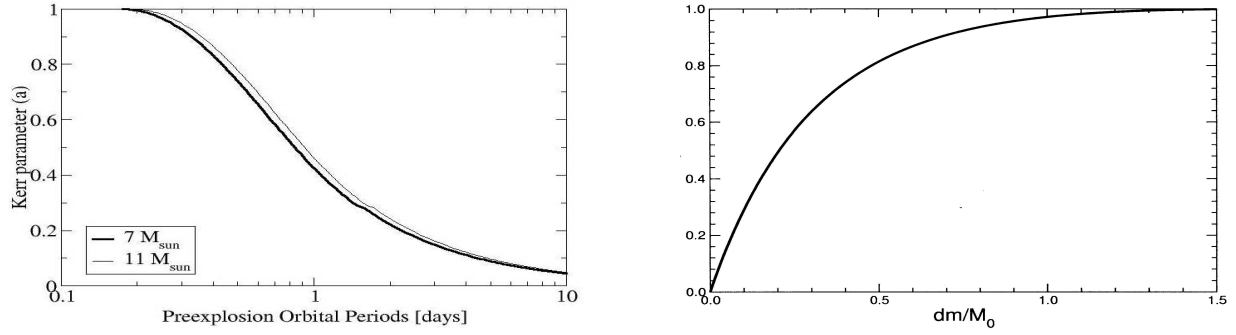


FIGURE 1. (Left) The BH spin a_* of the BH resulting from the collapse of a He star rotating synchronously with the orbit, as a function of orbital period [9]. The result depends very little on the mass of the He star, or on whether we use a simple polytrope or a more sophisticated model. (Right) Spinning up BHs. a_* is given in units of $[GM/c^2]$ and δm is the total rest mass of the accreted material. Note that M_0 is the mass of the non-rotating initial BH; we assumed that the last stable orbit corresponds to the marginally stable radius [4].

TABLE 1. Parameters at the time of formation of BH and at present time. Subindex 2 stands for values at the time BH is formed, whereas subindex *now* stands for recently measured values. The AML binaries lose energy by GWs, shortening the orbital period whereas the Nu binaries will experience mass loss from the donor star to the higher mass BH and, therefore, move to longer orbital periods.

Name	$M_{BH,2}$ [M_\odot]	$M_{d,2}$ [M_\odot]	$M_{BH,now}$ [M_\odot]	$M_{d,now}$ [M_\odot]	Model $a_{*,2}$	Measured a_*	$P_{Orbit,now}$ [days]	E_{BZ} [10^{51} ergs]
AML: with main sequence companion								
J1118+480	~ 5	< 1	6.0–7.7	0.09–0.5	0.8	-	0.169930(4)	~ 430
Vel 93	~ 5	< 1	3.64–4.74	0.50–0.65	0.8	-	0.2852	~ 430
J0422+32	6–7	< 1	3.4–14.0	0.10–0.97	0.8	-	0.2127(7)	500–600
1859+226	6–7	< 1	7.6–12		0.8	-	0.380(3)	500–600
GS1124–683	6–7	< 1	6.95(6)	0.56–0.90	0.8	-	0.4326	500–600
H1705–250	6–7	< 1	5.2–8.6	0.3–0.6	0.8	-	0.5213	500–600
A0620–003	~ 10	< 1	11.0(19)	0.68(18)	0.6	-	0.3230	~ 440
GS2000+251	~ 10	< 1	6.04–13.9	0.26–0.59	0.6	-	0.3441	~ 440
Nu: with evolved companion								
GRO J1655–40	~ 5	1–2	5.1–5.7	1.1–1.8	0.8	0.65–0.75	2.6127(8)	~ 430
4U 1543–47	~ 5	1–2	2.0–9.7	1.3–2.6	0.8	0.75–0.85	1.1164	~ 430
XTE J1550–564	~ 10	1–2	9.68–11.58	0.96–1.64	0.5	-	1.552(10)	~ 300
GS 2023+338	~ 10	1–2	10.3–14.2	0.57–0.92	0.5	-	6.4714	~ 300
XTE J1819–254	6–7	~ 10	8.73–11.69	5.50–8.13	0.2		2.817	10–12
GRS 1915+105	6–7	~ 10	14(4)	1.2(2)	0.2	> 0.98	33.5(15)	10–12
Cyg X–1	6–7	$\gtrsim 30$	~ 10.1	17.8	0.15	-	5.5996	5–6
Extragalactic								
LMC X–1	~ 40	~ 35	8.96–11.64	30.62 ± 3.22	~ 0.05	0.81–0.94	3.91	< 2
LMC X–3	7	4	5–11	6 ± 2	0.43	> 0.26	1.70	~ 155
M33 X–7	~ 90	~ 80	14.20–17.10	70.0 ± 6.9	~ 0.05	0.72–0.82	3.45	3–11

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